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Effects of level of protein and type of molasses on digesta kinetics and blood metabolites in sheep

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Abstract

Eight ruminally fistulated wethers were used in a replicated 4×4 latin square to investigate the effects of level of dietary protein (10 or 18%) and type of molasses (BM-sugarbeet molasses, or WSC-wood sugar molasses) on digesta kinetics and blood metabolites in sheep. Wethers were fed a basal diet of 70% chopped prairie hay:30% chopped barley straw (forage) and one of four treatment diets. Treatments were: (1) 10% CP and WSC, (2) 10% CP and BM, (3) 18% CP and WSC, and (4) 18% CP and BM. Diets were formulated to be iso-caloric using barley in the low protein diets to balance for energy. Soybean meal (SBM) was fed to meet the 10% CP and 18% CP protein treatments. Response variables included in vivo and in situ digestion, SBM and forage digesta kinetics, ruminal VFA concentrations, and blood metabolites. Lambs fed WSC tended ($P = 0.11$) to have greater IVDMD, ruminal isobutyrate, and valerate than lambs fed BM. In situ SBM and forage rate of digestion, particulate passage rates, retention time, intestinal transit time, total VFA concentration and acetate:propionate ratio did not differ between types of molasses ($P > 0.20$). Lambs fed the 18% CP diets consumed more feed, had a more rapid rate of SBM in situ digestion, lower ruminal pH, faster SBM and forage particulate passage, and lower SBM and forage retention time than lambs fed the 10% CP diet ($P < 0.10$). Total and individual VFA concentration were greater ($P = 0.001$) in lambs fed the 18% CP diet than lambs fed the 10% CP diet. Aspartate aminotransferase was greater in lambs fed BM than lambs fed WSC. Blood levels of creatinine, chloride, calcium, protein, lactate dehydrogenase, and cholesterol were lower ($P < 0.11$), and triglycerides and blood urea nitrogen higher ($P = 0.01$) in lambs fed the 18% CP diet than those fed the 10% CP diet. Level of dietary protein exerts much greater influence on digestibility and blood metabolites than type of molasses. However, WSC appears to be a suitable replacement for BM given equal price structure. © 1998 Elsevier Science B.V.

Keywords: Digestion; Particulate passage; VFA; Soybean meal; Molasses

1. Introduction

Wood sugar concentrates (WSC) are a byproduct of sulfite pulping, through which the wood is softened and defibered. Wood chips are cooked in a

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basic aqueous solution of basic oxide containing an excess of dissolved sulfur dioxide. The material binding the cellulose is made water soluble when digested. Wood sugars are separated by ultrafiltration. On a dry matter basis, the resultant WSC contains 38 to 44% total sugars, 28 to 30% lignosulfonate, and approximately 6% CP (Zinn, 1993). Hartnell and Satter (1978) suggested that the polyphenolic fraction in WSC bind with certain proteins to decrease their microbial degradation and increase the amount of dietary nitrogen that escapes rumen fermentation. Thomas et al. (1979) reported that WSC decreased in vitro rumen ammonia accumulations and decreased CP solubility. Zinn (1990) fed WSC (10.5% of diet DM) to steers in a metabolism study and found that WSC reduced total tract OM, DM, and N digestion when compared to similar diet without WSC. In a second study in which WSC and cane molasses were fed at 4% of the diet, Zinn (1993) reported no difference in total tract OM, DM, and N digestion. The objectives of this study were to investigate the effects of level of dietary protein (10 or 18%) and type of molasses (BM-sugarbeet molasses, or WSC-wood sugar molasses) on digesta kinetics and blood metabolites in sheep.

2. Materials and methods

The experimental protocol was reviewed and approved by the USDA-ARS Sheep Experiment Station Animal Care and Use Committee as outlined in the publication 'Guide for the Care and Use of Agricultural Animals in Agricultural Research and Teaching' (Consortium, 1988).

Eight ruminally fistulated wethers (average age 18 ± 0.2 months; average BW 50 ± 3.2 kg) were fed 70% chopped prairie hay:30% chopped barley straw (forage; Table 1) and one of four treatment diets including either WSC (wood sugar molasses) or BM (sugarbeet molasses) during four periods of a replicated 4×4 Latin square design. Treatments were: (1) W10 = 10% CP and WSC, (2) B10 = 10% CP and BM, (3) W18 = 18% CP and WSC, and (4) B18 = 18% CP and BM (Table 2). Based on the crude protein value of the forage, an amount of soybean meal (SBM) was fed to meet the 10% CP and 18% CP NRC (1985) protein requirements. Diets were formulated to be iso-caloric using barley in the low protein diets to balance for energy.

Table 1
Chemical composition (%DM) of forage, SBM, wood sugar concentrate (WSC), and sugar beet molasses (BM)

Item	Forage	SBM	WSC	BM	Barley
OM	93.0	91.0			
CP	8.5	48.6	6.3	15.3	14.0
ADF	40.6	4.2			
ADL	9.4	0.9			

Before the study began, wethers were adapted to diets and metabolism crates. Wethers were fed twice daily at 0700 and 1630 an amount of forage to allow ad libitum forage consumption. In addition, wethers received 100 g of molasses (50% of each WSC and BM; as fed basis) and 50 g of SBM which resulted in a diet that meet NRC (1985) CP requirement of 10%. After 10 days, actual forage intake was determined for each wether. During collection periods, each wether received 80% of its predetermined forage intake in all four periods. Both the BM and WSC were fed at a rate of 4% (as fed basis) of forage intake. Diets for each animal were hand mixed daily. The BM and WSC were sprayed onto the forage and SBM (or barley) as the mixing occurred.

Between periods, wethers were removed from the crates, confined outside as a group, and fed alfalfa hay for 7 days. After 7 days, wethers were placed back in the crates and fed the appropriate treatment diet for 5 days before collections began.

Table 2
Ingredient composition (DM basis) of average daily intake (g) for each treatment diet

g day^{-1}	18% CP		10% CP	
	WSC[a]	BM[b]	WSC[a]	BM[b]
Forage	967	967	967	967
SBM	278	277	13	12
BM	–	25	–	25
WSC	25	–	25	–
Barley	–	–	265	265
CP	229	231	128	130

[a](WSC) wood sugar concentrate.
[b](BM) sugar beet molasses.

2.1. Collection period

2.1.1. Days 1–5

At 0700 on day 1, wethers received a single dose via the rumen cannulas of 30 g ytterbium-labeled chopped forage (3048 ppm) and 25 g chromium-mordanted SBM (75.5 ppm). Chopped forage was labeled with $YbCl_3$ using the procedure described by Prigge et al. (1981). Forage was soaked in a solution of 2.5 g $YbCl_3$:1 l deionized water for 48 h and stirred three times daily, after which time the forage was strained and washed with water once every hour for 6 h. After washing, forage was dried at 50°C and ground to pass through a 2-mm screen.

SBM was mordanted using the procedure of Uden et al. (1980) by first drying for 48 h at 95°C. After drying, SBM was soaked in water and $Na_2Cr_2O_7$ containing Cr equal to 6–8% of the SBM weight. The material was then covered with foil and baked at 95°C for 24 h; then suspended in water and rinsed repeatedly until rinse water was clear. When rinsing was complete, the mordanted SBM was allowed to stand 1 h in water and approximately 100 g ascorbic acid kg^{-1} fiber. Rinsing was repeated until rinse water was clear, then SBM was dried at 50°C for 48 h or until dry.

Rectal grab samples were taken at 0, 4, 8, 12, 16, 20, 24, 28, 32, 36, 42, 48, 54, 60, 72, 84, 96, 108, and 120 h after dosing to determine the particulate passage rate of each feed. Samples were dried at 100°C and a dry matter factor determined for each sample. Dried samples were ground to pass through 1 mm screen for the determination of particulate passage rate.

Total fecal output was determined during this 5-day period using fecal collection bags. Feces were composited by wethers within period, weighed, and a subsample taken for later analysis of organic matter and dry matter. Rectal grab sample weights were included in the calculation of total fecal output.

2.1.2. Day 6 and 7

Digesta samples were collected via the rumen cannulas at 0800, 1100, 1400, and 1700 on day 6 and at 0900, 1200, 1500, and 1800 on day 7. Samples were strained through 40 mesh cambric bags and a 100 ml sample was obtained. Sample pH was determined, then samples were acidified (with 1 ml 7.2N H_2SO_4), composited by wethers within period, and frozen for later VFA analysis.

2.1.3. Day 8–10

In situ SBM and forage digestion in the rumen was determined using nylon bags (52 mm × 130 mm, pore size = 53 um) containing SBM or forage (3 g; ground to pass through a 2-mm screen). Bags were placed in the rumen of each wether on day 8 at 0700. Duplicate bags were removed from the rumen of each wether following 0-, (cold water rinse only) 4-, 8-, 12-, 24- or 48-h incubations. Blank bags also were removed at each collection time. Not all wethers were represented with blank bags at all collections; however, all treatments were represented at each collection time. When bags were removed from the rumen, they were rinsed in cold water, dried at 100°C for 24 h, desiccated, and weighed.

2.2. Blood

Wethers were fitted with in-dwelling jugular cannulas 24 h before samples were taken. Blood samples were taken at 30 min intervals for 1 h pre- and post-feeding every morning. Additional blood samples followed a similar collection pattern as fecal collections and were collected at 1000, 1400, 1800, and 2200 h on day 1 and 0200, 0600, 1000, 1400, 1800, and 2200 h on day 2. All samples were centrifuged for 10 min at $2500 \times g$, and the serum frozen for later composition and/or analysis. The morning post-feed blood samples (0730 and 0800) were not composited; however, the morning pre-feed blood samples (0600 and 0630) were composited by animal within the day. All other blood samples were composited by animal within the day.

2.3. Laboratory procedures

Dry matter, organic matter, and Kjeldahl-N (feed samples only) of feed and fecal samples were determined by AOAC (1984) procedures. Neutral detergent fiber, ADF, and ADL of SBM and forage were determined by the non-sequential procedures of Goering and Van Soest (1970). Feed values are reported in Table 1.

Volatile fatty acid analysis was performed using the method described by Erwin et al. (1961). Five ml

of preserved rumen fluid was placed in a 15 ml centrifuge tube, then 1 ml 25% o-metaphosphoric acid was added. Tubes were allowed to stand for 30 min then centrifuged for 10 min at $3000 \times g$. The supernatant was drawn off for analysis of VFA by gas chromatography. Columns were 6 feet by 2 mm I.D. acid-washed glass. Temperatures were: injector = 170°C; column = 125°C; and detector = 175°C (FID). Flow rates were: N = 20 ml min^{-1}; air = 300–400 ml min^{-1} at 34 psi; and H = 30 ml min^{-1} at 12 psi.

Ytterbium and chromium digestions were performed using a modification of the procedure described by Bellanger (1987). A 0.5-g fecal or feed sample was ashed in a silica basin at 500°C for 10 h, then 5 ml of 5% (v/v) HNO_3 was added to the cooled sample. The samples were washed completely with DDI water into a 50 ml volumetric flask and brought to volume with DDI water. Atomic absorption spectrophotometry was used to determine both chromium (flame) and ytterbium (graphite furnace). Passage rate was analyzed using the methods described by Krysl et al. (1988).

Blood samples or composites were analyzed on a Technicon SMAC-3 analyzer. Both the morning pre- and post-feeding samples or composites were analyzed only for blood urea nitrogen (BUN) concentration. All other composites were analyzed for glucose hexokinase, blood urea nitrogen, creatinine, uric acid, sodium, potassium, chloride, calcium, phosphates, iron, protein, albumin, total and direct bilirubin, alkaline phosphatase, aspartate aminotransferase, lactate dehydrogenase, gamma glutamyl transpepsidase, cholesterol, and triglycerides.

2.4. Statistical procedure

The model for DMI, in vivo DMD, forage and SBM particulate passage rate, total tract retention time, intestinal transit time, ruminal VFA concentrations, and blood metabolites included effects of period, square, protein level, type of molasses, and level of protein by type of molasses interaction. Ruminal pH, in situ forage and SBM DMD, and BUN were analyzed using the SAS (1988) repeated measures analysis. The model include the effects of period, time, level of protein, type of molasses, and level of protein by type of molasses interaction. Variables were tested using the residual error term.

3. Results and discussion

3.1. Intake and digesta kinetics

Although wethers were fed a restricted amount of forage based on pre-study forage intake, intake of forage by wethers receiving the 18% CP diet was greater ($P = 0.01$) than lambs fed the 10% CP diet (Table 3). Substituting barley for SBM (Table 2) to maintain the iso-caloric relationship between the two protein treatments is the mostly likely reason why lambs receiving the 10% CP diet consumed less feed during the collection period than when ad libitum intake levels were calculated using a 10% CP diet before collections began. Bowman and Sanson (1996) reviewed numerous publications that demonstrate the negative associative affects of feeding non-structural carbohydrates (i.e., grain) on forage DMI.

Dry matter intake, passage rate, retention time, and intestinal transit time did not differ between types of molasses ($P > 0.22$; Table 4). SBM and forage passage rate were greater ($P < 0.10$) and SBM and forage total tract retention time were lower

Table 3
Dry matter intake, in vivo digestion, passage rate, retention time, and intestinal transit time of chromium-mordanted SBM and ytterbium-labeled forage dosed to wethers receiving either 18 or 10% CP diet

	18% CP	10% CP	SEM	*P*
DMI, g $lamb^{-1}$ day^{-1} [a]	1205.4	887.7	43.66	0.01
In vivo DM digestion, %	58.3	57.3	1.99	0.74
SBM				
Particulate passage rate, % h^{-1}	5.2	4.4	0.30	0.10
Total tract retention time, h[b]	41.0	47.1	2.06	0.05
Intestinal transit time, h[b]	16.5	18.5	1.08	0.19
Forage				
Particulate passage rate, % h^{-1}	4.6	4.1	0.15	0.02
Total tract retention time, h	45.3	50.4	1.25	0.01
Intestinal transit time, h	18.8	20.4	0.94	0.23

[a]Although ad libitum intake was determined before the study and an 80% restricted intake was calculated for each lamb, rejected feed resulted in differences in intake.
[b]Level of CP by type of molasses interaction ($P = 0.05$).

Table 4
Dry matter intake, in vivo digestion, passage rate, retention time, and intestinal transit time of chromium-mordanted SBM and ytterbium-labeled forage dosed to wethers receiving either wood sugar concentrates (WSC) or sugar beet molasses

	(BM)	WSC	SEM	*P*
DMI, g lamb^{-1} day^{-1}[a]	1073.4	1019.7	43.66	0.40
In vivo DM digestion, %	55.4	60.2	1.99	0.11
SBM				
Particulate passage rate, % h^{-1}	4.8	4.8	0.30	0.91
Total tract retention time, h[b]	44.6	43.5	2.06	0.70
Intestinal transit time, h[b]	18.1	16.8	1.08	0.42
Forage				
Particulate passage rate, % h^{-1}	4.4	4.2	0.15	0.34
Total tract retention time, h	47.9	47.7	1.25	0.89
Intestinal transit time, h	20.4	18.8	0.94	0.22

[a]Although ad libitum intake was determined before the study and an 80% restricted intake was calculated for each lamb, rejected feed resulted in differences in intake.
[b]Level of CP by type of molasses interaction ($P = 0.05$).

($P < 0.05$) for lambs fed the 18% CP diet compared to lambs fed the 10% CP diet. Caton et al. (1988) reported that particulate mean retention time was lower and passage rate (k_1) was greater in steers receiving a higher protein diet than non-supplemented steers. In our study, level of dietary CP and DMI are confounded. Grovum and Williams (1977) stated that increasing level of intake by ruminants fed forage-based diets increases turnover rate of particulate digesta from the rumen. However, Burns et al. (1991) concluded that differences in DMI by grazing steers were due to differences in diet in vitro DM disappearance rather than to differences in digesta kinetics.

Level of CP by type of molasses interactions were detected for SBM total tract retention time and intestinal transit time. Total tract retention time was greatest for B10 (50.5 h; $P = 0.08$), intermediate for W10 and W18 (43.5 and 43.3 h, respectively), and lowest for B18 (38.6 h; $P = 0.11$). Intestinal transit time was greatest for B10 (20.7; $P = 0.05$), intermediate for W18 and W10 (17.5 and 16.2 h, respectively), and tended to be lowest for B18 (15.5 h). No other interactions were detected ($P > 0.10$) for intake and digesta kinetic variables.

In vivo DMD tended ($P = 0.11$) to be greater in lambs fed WSC compared to lambs fed BM. In vivo DMD and intestinal transit time for SBM and forage did not differ ($P > 0.19$) between CP levels. In situ forage DMD did not differ ($P > 0.20$) between either level of CP or type of molasses (Fig. 1). However, in situ SBM DMD was greater ($P = 0.01$) in lambs fed the 18% CP diet than lambs fed the 10% CP diet (Fig. 2). Hartnell and Satter (1978) suggested that feeding WSC decreased microbial degradation of dietary CP and increased the amount of dietary N escaping rumen fermentation. In our study, in situ SBM DMD was not influenced ($P = 0.97$) by type of molasses, indicating no effect on microbial function and N fermentation. Caton et al. (1988) also reported no difference in in situ rate of digestion of esophageally collected forage in steers grazing dormant blue grama rangeland and either supplemented

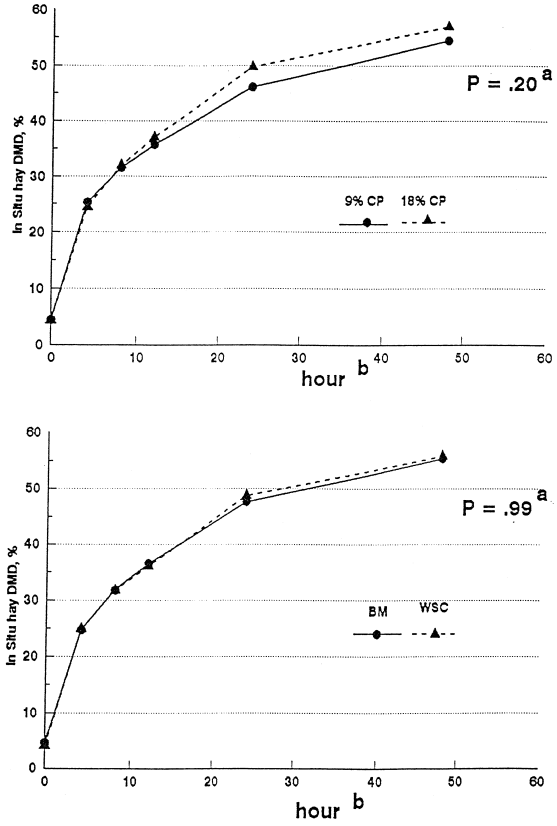

Fig. 1. In situ DM forage digestion in wethers fed 10 or 18% CP diets with wood sugar concentrates (WSC) or sugar beet molasses (BM). Pooled SE of the LS means is 0.86%. [a]*P* value associated with repeated measures mean comparison. [b]Hours of incubation.

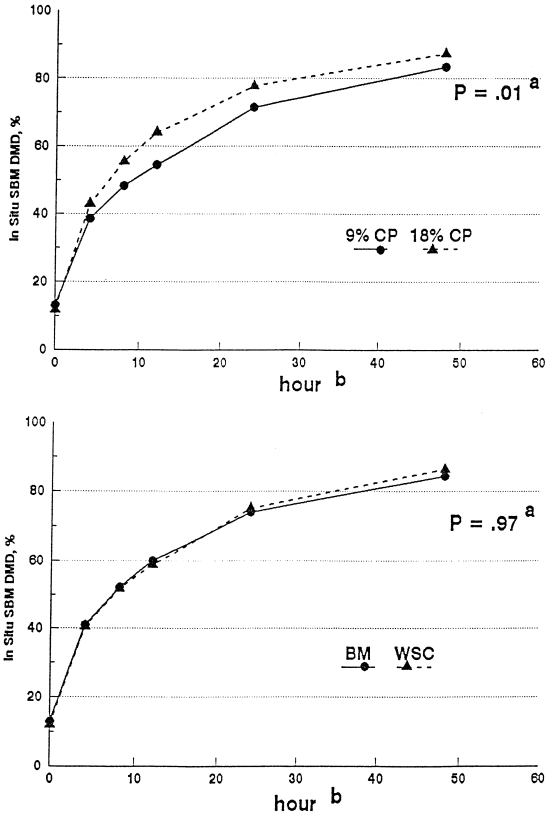

Fig. 2. In situ DM SBM digestion in wethers fed 10 or 18% CP diets with wood sugar concentrates (WSC) or sugar beet molasses (BM). Pooled SE of the LS means is 1.04% [a]*P* value associated with repeated measures mean comparison. [b]Hours of incubation.

or non-supplemented. These researchers did report, however, that in vitro forage digestion was greater in supplemented than non-supplemented steers.

The reason for the tendency for improved in vivo DMD in lambs fed WSC is not clear. Although molasses is usually added to the diet as a conditioner and to enhance intake, its nutritive value is important. Typically, WSC are lower in sugars and digestible nutrients than BM. Zinn (1990) fed 10.5% WSC (DM basis) to steers in a metabolism study and found that WSC reduced total tract OM, DM, and N digestion when compared to a similar diet without WSC. Zinn (1990) attributes the decrease in N digestion to the high level of lignosulfonate due to the high levels (10.5% of diet DM) of WSC. In a second study in which WSC and cane molasses were fed at 4% of the diet, Zinn (1993) reported no difference in total tract OM, DM, and N digestion; however, the quantity of ammonia N leaving the abomasum was lower in steers fed WSC than steers fed the cane molasses diet. In the feedlot portion of this study, Zinn (1993) fed either cane molasses or WSC to feedlot steers at 4% of diet on DM basis. He found no difference in DMI, gain, or the DMI:gain ratio. However, when WSC and cane molasses were fed at 8% of the diet, the DMI:gain was lower for the cane molasses fed steers. Hartnell and Satter (1978) compared rations for lambs containing SBM extruded with either 10% WSC or cane molasses. These researchers found no difference in DMI, or DM or CP digestion.

3.2. Ruminal pH and VFA concentration

Ruminal pH did not differ ($P = 0.68$) between types of molasses (Fig. 3). Lambs fed the 18% CP

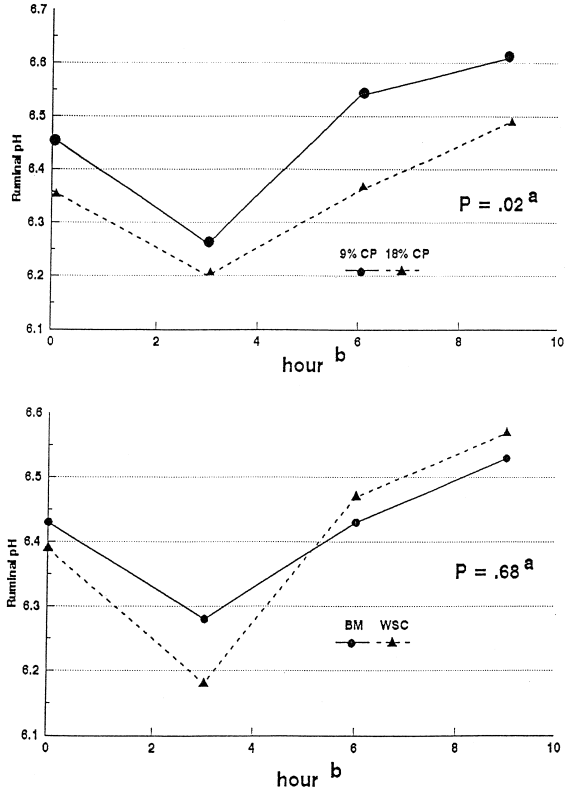

Fig. 3. Ruminal pH in wethers fed 10 or 18% CP diets with wood sugar concentrates (WSC) or sugar beet molasses (BM). Pooled SE of the LS means is 0.04. [a]*P* value associated with repeated measures mean comparison. [b]Hours post-feeding.

diet had lower ($P = 0.02$) ruminal pH than lambs fed the 10% CP diet. Guthrie and Wagner (1988) also reported a linear decrease in ruminal pH with increasing level of SBM in prairie hay diets fed to steers. The findings of both these authors and our study demonstrate that increased levels of dietary protein result in increased energy status. This is due to greater ruminal fermentation, as evidenced by the levels of total ruminal VFA production in the 18% CP diet compared with the 10% diets (Table 3).

Level of dietary protein had a major effect on VFA concentrations. Acetate, propionate, isobutyrate, butyrate, isovalerate, valerate, and total VFA concentrations were greater ($P = 0.001$) in wethers fed the 18% CP diet than those receiving the 10% CP diet (Table 5). Acetate:propionate ratio did not differ ($P = 0.33$) between dietary protein treatments. Because lambs fed the 18% CP diet consumed more feed, the differences in ruminal VFA concentrations are confounded with level of dietary CP and DMI. However, we speculated that the 18% CP diet improved rumen microbial conditions which resulted in greater intake. Therefore, we suggest that differences in VFA concentrations are attributable to the level of dietary CP rather than level of DMI.

Level of CP by type of molasses interactions were detected for propionate, butyrate, valerate, and total VFA concentrations ($P < 0.10$). In all cases, the ranking was W18, B18, B10, and W10. Differences ($P < 0.03$) between B18 and B10 were detected in all interactions. No differences ($P > 0.16$) were detected between B10 and W10. The difference between W18 and B18 was significant ($P = 0.01$) only in valerate concentration. No other interactions were detected ($P > 0.10$) in ruminal pH and VFA concentration variables.

Table 5
Rumen VFA concentrations (mmol l^{-1}) for lambs receiving either 18 or 10% CP diet

Item	18% CP	10% CP	SEM	*P*
Acetate	57.2	46.6	1.70	0.001
Propionate[a]	14.5	11.5	0.41	0.001
Isobutyrate	0.9	0.4	0.05	0.001
Butyrate[b]	9.2	6.8	0.30	0.001
Isovalerate	1.3	0.7	0.06	0.001
Valerate[b]	1.0	0.6	0.03	0.001
Total[a]	84.2	66.6	2.39	0.001
Acetate:propionate	4.0	4.1	0.08	0.33

[a]Level of CP by type of molasses interaction ($P < 0.10$).
[b]Level of CP by type of molasses interaction ($P < 0.05$).

Table 6
Rumen VFA concentrations (mmol l^{-1}) for lambs receiving either wood sugar concentrates (WSC) or sugar beet molasses (BM)

Item	BM	WSC	SEM	*P*
Acetate	52.2	51.6	1.70	0.78
Propionate[a]	13.1	12.9	0.41	0.79
Isobutyrate	0.6	0.7	0.05	0.08
Butyrate[b]	7.9	8.0	0.30	0.79
Isovalerate	1.0	1.0	0.06	0.25
Valerate[b]	0.7	0.9	0.03	0.01
Total[a]	75.6	75.2	2.39	0.92
Acetate:propionate	4.0	4.0	0.08	0.98

[a]Level of CP by type of molasses interaction ($P < 0.10$).
[b]Level of CP by type of molasses interaction ($P < 0.05$).

Lambs fed WSC had greater ($P < 0.10$) isobutyrate and valerate concentrations than wethers fed BM (Table 6). Other VFA concentrations did not differ between type of molasses treatments. The reason isobutyrate tended to be greater and valerate was greater in lambs fed WSC than lambs fed BM diets is not understood. However, type of molasses had no effect on total VFA concentrations and thus, these differences may be inconsequential. Hartnell and Satter (1978) compared rations containing SBM extruded with either 10% WSC or cane molasses. They reported no difference in ruminal total VFA production. Zorrilla-Rios et al. (1991) fed steers wheat straw based diets and 0, 150, or 500 g day^{-1} of SBM. These researchers found total VFA, butyrate, isobutyrate, valerate, and isovalerate were greatest for the 500 g treatment. Propionate was greatest in steers fed the 0 SBM diet and acetate was greatest in steers fed the 150 g day^{-1} SBM diet. Because VFA are the primary source of metabolizable energy for ruminants, we conclude that the 18% CP diet increased the dietary energy status of the lamb.

3.3. Blood metabolites

Blood levels of creatinine, chloride, calcium, protein, lactate dehydrogenase, and cholesterol tended to be lower ($P < 0.11$) in lambs fed the 18% CP diet than those fed the 10% CP diet (Table 7). Kephart

Table 7
Blood metabolites in lambs receiving either 18 or 10% CP diet

Item	18% CP	10% CP	SEM	*P*
Glucose hexokinase, mg dl^{-1}	64.6	62.5	1.10	0.18
Blood urea nitrogen, mg dl^{-1}	24.2	13.0	1.04	0.01
Creatinine, mg dl^{-1}	0.9	1.1	0.02	0.01
Sodium, mEq l^{-1}	152.4	157.4	1.55	0.03
Potassium, mEq l^{-1}	6.7	6.8	0.11	0.26
Chloride, mEq l^{-1}	115.8	118.8	0.93	0.01
Calcium, mg dl^{-1}	10.8	11.6	0.25	0.03
Phosphorus, mg dl^{-1}	6.1	5.7	0.20	0.19
Iron, ug dl^{-1}	124.1	126.1	6.11	0.81
Protein, g dl^{-1}	8.4	8.9	0.19	0.11
Albumin, g dl^{-1}	3.8	4.0	0.09	0.15
Total bilirubin, mg dl^{-1}	0.1	0.1	0.01	0.28
Alkaline phosphatase, U l^{-1}	149.1	144.4	5.90	0.57
Aspartate aminotransferase, U l^{-1} [a]	90.3	73.8	7.19	0.11
Lactate dehydrogenase, U l^{-1}	293.5	327.3	9.23	0.02
Gamma glutamyl transpepsidase, U l^{-1}	65.4	71.1	2.90	0.17
Cholesterol, mg dl^{-1}	53.7	64.1	2.19	0.01
Triglycerides, mg dl^{-1} [a]	9.8	5.6	0.86	0.01

[a] Level of CP by type of molasses interaction ($P = 0.08$).

and Sherritt (1990) reported no difference in plasma potassium, sodium, or chloride in pigs fed 10.9 and 16.9% CP diets, which conflicts with the results of this study indicating lambs fed the 18% diet had lower serum chloride levels. No differences in serum potassium or sodium were noted between the 10% and 18% CP diets (Table 7).

Level of CP by type of molasses interactions were detected for aspartate aminotransferase (AST) and triglycerides. Blood AST was 111.4, 76.1, 71.4, and 69.3 U l^{-1} for B18, B10, W10, and W18, respectively. The P value associated with the difference in AST between B18 and B10 was $P = 0.03$. No other differences were detected ($P > 0.73$). Blood triglycerides levels were 10.0, 9.5, 7.6 and 3.6 mg dl^{-1} for W18, B18, B10, and W10, respectively. Differences were detected ($P < 0.03$) between B18 and B10, and between B10 and W10. No other interactions were detected ($P > 0.10$) in blood metabolite variables.

Protein and gamma glutamyl transpepsidase (GGT) tended to be greater ($P < 0.13$) and AST was lower ($P = 0.03$) in wethers fed WSC compared to wethers fed BM (Table 8). Serum proteins are synthesized in the liver (Kaneko, 1989). Thus, the tendency for a difference in total protein indicates that liver function differed between both the CP and molasses treatments.

Thomas et al. (1979) reported that WSC decreased in vitro rumen ammonia concentration. Although we did not measure rumen ammonia, type of molasses had no effect ($P = 0.88$) on blood urea nitrogen when measured from 1 h pre- to 1 h post-feeding (Fig. 4). Lambs fed the 18% CP diet had a greater ($P = 0.01$) BUN over this same period than lambs fed the 10% CP diet. Increased BUN concentration observed with increased dietary protein is caused by increased absorption of ruminal ammonia, resulting in greater quantities of ammonia being detoxified in the liver to form urea. Thomas et al. (1988) reported that serum albumin and blood urea nitrogen reflected the dietary protein intake. Rusche et al. (1993) reported that feeding high escape CP sources decreased plasma glucose and BUN. Greater concentration of BUN would be expected when protein with greater ruminal degradation potential was fed. Zorrilla-Rios et al. (1991) working with steers fed wheat straw and 0, 150, or 500 g day^{-1} of SBM found plasma urea N increased with increasing amount of SBM.

Blood creatinine is a product of nitrogen metabolism. The rate of blood creatinine production may be considered an index of endogenous protein

Table 8
Blood metabolites in lambs receiving either wood sugar concentrates (WSC) or sugar beet molasses (BM)

Item	BM	WSC	SEM	*P*
Glucose hexokinase, mg dl^{-1}	63.3	63.8	1.10	0.79
Blood urea nitrogen, mg dl^{-1}	18.4	18.8	1.04	0.77
Creatinine, mg dl^{-1}	1.0	1.0	0.02	0.22
Sodium, mEq l^{-1}	153.9	155.8	1.47	0.40
Potassium, mEq l^{-1}	6.8	6.7	0.11	0.51
Chloride, mEq l^{-1}	116.9	117.1	0.93	0.86
Calcium, mg dl^{-1}	11.0	11.4	0.25	0.19
Phosphorus, mg dl^{-1}	5.9	5.9	0.20	0.83
Iron, ug dl^{-1}	128.8	121.4	6.11	0.39
Protein, g dl^{-1}	8.4	8.9	0.19	0.13
Albumin, g dl^{-1}	3.8	3.9	0.09	0.53
Total bilirubin, mg dl^{-1}	0.1	0.1	0.01	0.28
Alkaline phosphatase, U l^{-1}	151.2	142.4	5.90	0.30
Aspartate aminotransferase, U l^{-1} [a]	93.8	70.3	7.19	0.03
Lactate dehydrogenase, U l^{-1}	312.4	308.4	9.23	0.76
Gamma glutamyl transpepsidase, U l^{-1}	64.8	71.6	2.90	0.11
Cholesterol, mg dl^{-1}	58.3	59.4	2.19	0.71
Triglycerides, mg dl^{-1} [a]	8.6	6.8	0.86	0.16

[a] Level of CP by type of molasses interaction ($P = 0.08$).

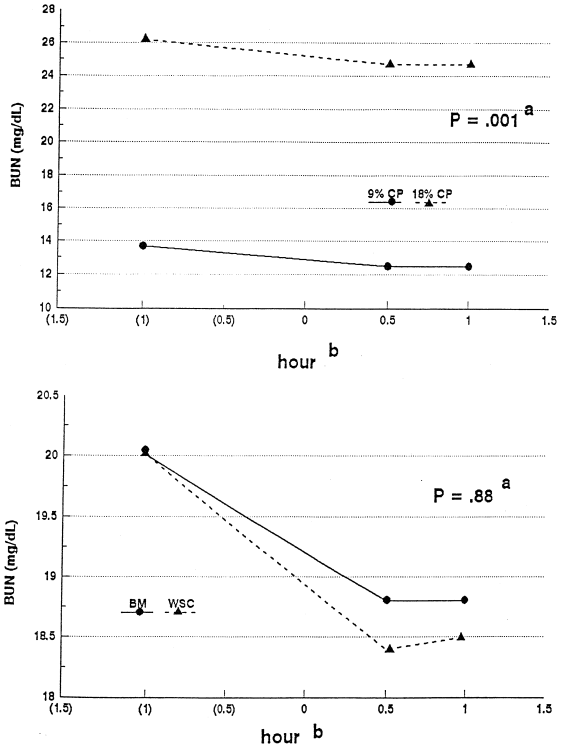

Fig. 4. Blood urea nitrogen in wethers fed 10 or 18% CP diets with wood sugar concentrates (WSC) or sugar beet molasses (BM). Pooled SE of the LS means is 1.02 mg dl^{-1}. [a]*P* value associated with repeated measures mean comparison. [b]0 hour = feeding time, hours in parentheses are pre-feeding and without parentheses are post-feeding.

catabolism. Lambs fed the 10% CP diet tended ($P = 0.11$) to have greater levels of serum protein and had greater ($P = 0.01$) creatinine levels than lambs fed the 18% CP diet. Although not significant, Zorrilla-Rios et al. (1991) working with steers fed wheat straw and 0, 150, or 500 g day^{-1} of SBM also reported a trend for a decrease in plasma total protein with increasing dietary CP.

Serum cholesterol is primarily synthesized and metabolized in the liver (Bartley, 1989). Solomon et al. (1991) reported the highest tissue level of cholesterol in lambs fed SBM, lowest in lambs fed rapeseed meal, and intermediate in lambs fed SBM-rapeseed meal. Park (1985) found depressed concentration of total serum cholesterol in calves fed a high protein diet as compared to their low protein counterparts. Studies with humans, monkeys, chicks, and pigs have also found elevated cholesterol levels resulting from low protein diets (Mann, 1960; Beveridge et al., 1963; Johnson et al., 1958; Leveille et al., 1962; Hutagalung et al., 1969; Baker et al., 1968; Pond et al., 1960).

Triglycerides are lipids that store energy in adipose tissue of the animal. Lambs fed the 18% CP diet had greater ($P = 0.01$) blood levels of triglycerides and tended ($P = 0.11$) to have greater levels of aspartate aminotransferase (AST) than lambs fed the 10% CP diet (Table 7).

4. Conclusions

Increased intake and greater digestibility were found using diets greater in protein. These diets also resulted in a more favorable microbial environment in the rumen, and therefore, better utilization of feed and improved energy status. Although there was a tendency for improved digestibility in wethers fed WSC in our study, these results conflict with other research pertaining to feeding WSC, and it appears that level of dietary protein exerts much greater influence on digestibility and blood metabolites than type of molasses. Although WSC appears to be a suitable replacement for BM given equal price structure, it did not affect either rate of passage or ruminal digestion of SBM.

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